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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

INVENTOR(S)						
Given Name (first and middle (if any))		Family Name or Surname		Residence (City and either State or Foreign Country)		
David		Frank		Scarborough, ONTARIO, CANADA		
<input checked="" type="checkbox"/> Additional inventors are being named on the _____, separately numbered sheets attached hereto						
TITLE OF THE INVENTION (500 characters max)						
End Plate For An Electrochemical Cell Stack						
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Address		5985 MCLAUGHLIN ROAD				
Address						
City		MISSISSAUGA	State	ONTARIO	ZIP	L5R 1B8
Country		CANADA	Telephone	(905) 361-3660	Fax	(905) 361-3626
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The invention was made by an agency of the United States Government or under a contract with an agency of the United States Government.						
<input checked="" type="checkbox"/> No.						
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Respectfully submitted,

SIGNATURE Steven Yang

TYPED or PRINTED NAME Steven Yang

TELEPHONE (905) 361-3652

Date 8/15/03

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Docket Number:

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INVENTOR(S)/APPLICANT(S)		
Given Name (first and middle (if any))	Family or Surname	Residence (City and either State or Foreign Country)
Nathaniel Ian	Joos	Toronto, Ontario, Canada
Mario	Dzamarija	Toronto, Ontario, Canada
Ricardo	Bazzarella	Cambridge, Ontario, Canada

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END PLATE FOR AN ELECTROCHEMICAL CELL STACK

FIELD OF INVENTION

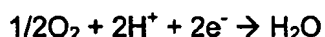
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The present invention relates to end plates for electrochemical cell stack.

BACKGROUND TECHNOLOGY

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A fuel cell is an electrochemical device that produces an electromotive force by bringing the fuel (typically hydrogen) and an oxidant (typically air) into contact with two suitable electrodes and an electrolyte. A fuel, such as hydrogen gas, for example, is introduced at a first electrode where it reacts electrochemically in the presence of the electrolyte to produce electrons and cations in the first electrode. The electrons are circulated from the first electrode to a second electrode through an electrical circuit connected between the electrodes. Cations pass through the electrolyte to the second electrode. Simultaneously, an oxidant, such as oxygen or air is introduced to the second electrode where the oxidant reacts electrochemically in presence of the electrolyte and catalyst, producing anions and consuming the electrons circulated through the electrical circuit; the cations are consumed at the second electrode. The anions formed at the second electrode or cathode react with the cations to form a reaction product. The first electrode or anode may alternatively be referred to as a fuel or oxidizing electrode, and the second electrode may alternatively be referred to as an oxidant or reducing electrode. The half-cell reactions at the two electrodes are, respectively, as follows:



30

The external electrical circuit withdraws electrical current and thus receives electrical power from the fuel cell. The overall fuel cell reaction produces

electrical energy as shown by the sum of the separate half-cell reactions written above. Water and heat are typical by-products of the reaction.

In practice, fuel cells are not operated as single units. Rather, fuel cells
5 are connected in series, stacked one on top of the other, or placed side by side,
to form what is usually referred to as a fuel cell stack. The fuel and oxidant are
directed through manifolds to the electrodes, while cooling is provided either by
the reactants or by a cooling medium. Also within the stack are current collectors,
cell-to-cell seals and insulation, with required piping and instrumentation provided
10 externally of the fuel cell stack. The stack and associated hardware make up a
fuel cell module.

A fuel cell stack is completed by two end plates provided on two ends
of the stack. End plates provide connection between the internal flow channels of
15 the stack and external sources of process fluids, i.e. fuel, oxidant and coolant.
End plates are usually provided with connection ports for this purpose. Process
fluids flow through respective connection ports into and out of the fuel cells stack.

In order to compress the fuel cells together, pressure is applied to the
20 ends of the stack and hence, the end plates. The pressure can be applied using
a certain clamping mechanism. This requires the end plate to be robust.
Conventional end plates are made of metal and are thick and heavy in order to
provide the robustness. This is highly undesirable as the current trend of
research and development is to make thinner and lighter fuel cells and more
25 compact stacks.

Therefore, there remains a need for an end plate that is stiff, light
weight and robust.

SUMMARY OF THE INVENTION

An end plate for an electrochemical cell stack, comprises an outer face and an inner face, wherein a plurality of cavities are provided on the inner face. The inner face comprises a central region and a peripheral region surrounding the central region and a first plurality of cavities are provided in the central region forming an array of cavities. The end plate further comprises a second plurality of cavities in the peripheral region.

BRIEF DESCRIPTION OF DRAWINGS

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For a better understanding of the present invention, and to show more clearly how it may be carried into effect, reference will now be made, by way of example, to the accompanying drawings, which show preferred embodiments of the present invention and in which:

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Figure 1 illustrates an exploded perspective view of a fuel cell unit located within a fuel cell stack;

Figure 2 illustrates a first perspective view of a first embodiment of an end plate in accordance with the present invention;

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Figure 3 illustrates a second perspective view of the first embodiment of the end plate in accordance with the present invention;

Figure 4 illustrates a front elevational view of the first embodiment of the end plate in accordance with the present invention;

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Figure 5 illustrates a side elevational view of the first embodiment of the end plate in accordance with the present invention;

Figure 6 illustrates a top view of the first embodiment of the end plate in accordance with the present invention;

Figure 7 illustrates a back elevational view of the first embodiment of the end plate in accordance with the present invention;

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Figure 8 illustrates a sectional view of the first embodiment of the end plate in accordance with the present invention, along line E-E of Figure 7;

Figure 9 illustrate a sectional view of the first embodiment of the end plate in accordance with the present invention, along line A-A of Figure 4;

Figure 10 illustrates a sectional view of the first embodiment of the end plate in accordance with the present invention, along line B-B of Figure 7;

5 Figure 11 illustrates a first perspective view of a second embodiment of the end plate in accordance with the present invention;

Figure 12 illustrates a second perspective view of the second embodiment of the end plate in accordance with the present invention;

10 Figure 13 illustrates a front elevational view of the second embodiment of the end plate in accordance with the present invention;

Figure 14 illustrates a back elevational view of the second embodiment of the end plate in accordance with the present invention;

Figure 15 illustrates a side elevational view of the second embodiment of the end plate in accordance with the present invention;

15 Figure 16 illustrates a top view of the second embodiment of the end plate in accordance with the present invention;

Figure 17 illustrates a sectional view of the second embodiment of the end plate in accordance with the present invention, along line C-C of Figure 14;

20 Figure 18 illustrates a sectional view of the second embodiment of the end plate in accordance with the present invention, along line D-D of Figure 14;

Figure 19 illustrates a first perspective view of a third embodiment of the end plate in accordance with the present invention;

Figure 20 illustrates a second perspective view of a third embodiment of the end plate in accordance with the present invention;

25 Figure 21 illustrates a front elevational view of the third embodiment of the end plate in accordance with the present invention;

Figure 22 illustrates a back elevational view of the third embodiment of the end plate in accordance with the present invention;

30 Figure 23 illustrates a side elevational view of the third embodiment of the end plate in accordance with the present invention;

Figure 24 illustrates a top view of the third embodiment of the end plate in accordance with the present invention;

Figure 25 illustrates a sectional view of the third embodiment of the end plate in accordance with the present invention, along line F-F of Figure 21;

5 Figure 26 illustrates a sectional view of the third embodiment of the end plate in accordance with the present invention, along line G-G of Figure 22;

Figure 27 illustrates a sectional view of the third embodiment of the end plate in accordance with the present invention, along line H-H of Figure 22;

10 Figure 28 illustrates a first perspective view of a fourth embodiment of the end plate in accordance with the present invention;

Figure 29 illustrates a second perspective view of the fourth embodiment of the end plate in accordance with the present invention;

Figure 30 illustrates a front elevational view of the fourth embodiment of the end plate in accordance with the present invention;

15 Figure 31 illustrates a back elevational view of the fourth embodiment of the end plate in accordance with the present invention;

Figure 32 illustrates a side elevational view of the fourth embodiment of the end plate in accordance with the present invention;

20 Figure 33 illustrates a top view of the fourth embodiment of the end plate in accordance with the present invention;

Figure 34 illustrates a sectional view of the fourth embodiment of the end plate in accordance with the present invention, along line I-I of Figure 31;

25 Figure 35 illustrates a sectional view of the fourth embodiment of the end plate in accordance with the present invention, along line J-J of Figure 31; and

Figure 36 illustrates a perspective view showing the assembly of an end plate, an insulator plate and a terminal plate, in accordance with the present invention.

30 **DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS**

The present invention relates to end plates for electrochemical cells. Hereinafter, the present invention will be described in detail by taking a PEM fuel cell as an example. It is to be understood that the present invention has applications not limited to PEM fuel cells, but rather any type of electrochemical cells, such as electrolyzers.

Referring first to Figure 1, this shows an exploded perspective view of a single fuel cell unit 100 located within a fuel cell stack according to the present invention. It is to be understood that while a single fuel cell unit 100 is detailed below, in known manner the fuel cell stack will usually comprise a plurality of fuel cells stacked together. Each fuel cell of the fuel cell unit 100 comprises an anode flow field plate 120, a cathode flow field plate 130, and a membrane electrode assembly (MEA) 124 disposed between the anode and cathode flow field plates 120, 130. Each reactant flow field plate has an inlet region, an outlet region, and open-faced channels to fluidly connect the inlet to the outlet, and provide a way for distributing the reactant gases to the outer surfaces of the MEA 124. The MEA 124 comprises a solid electrolyte (i.e. a proton exchange membrane) 125 disposed between an anode catalyst layer (not shown) and a cathode catalyst layer (not shown). A first gas diffusion layer (GDL) 122 is disposed between the anode catalyst layer and the anode flow field plate 120, and a second GDL 126 is disposed between the cathode catalyst layer and the cathode flow field plate 130. The GDLs 122, 126 facilitate the diffusion of the reactant gas, either the fuel or oxidant, to the catalyst surfaces of the MEA 124. Furthermore, the GDLs enhance the electrical conductivity between each of the anode and cathode flow field plates 120, 130 and the membrane 125.

Still referring to Figure 1, hereinafter the designations "front" and "rear" with respect to the anode and cathode flow field plates 120, 130 indicate their orientation with respect to the MEA 124. Thus, the "front" face indicates the side facing towards the MEA 124, while the "rear" face indicates the side facing away from the MEA 124. A first current collector plate 116 abuts against the rear face

of the anode flow field plate 120. Similarly, a second current collector plate 118 abuts against the rear face of the cathode flow field plate 130. First and second insulator plates 112, 114 are located immediately adjacent the first and second current collector plates 116, 118, respectively. First and second end plates 102, 104 are located immediately adjacent the first and second insulator plates 112, 114, respectively. Pressure may be applied on the end plates 102, 104 to press the unit 100 together. Moreover, sealing means are usually provided between each pair of adjacent plates. Preferably, a plurality of tie rods 131 may also be provided. The tie rods 131 are screwed into threaded bores in the anode endplate 102, and pass through corresponding plain bores in the cathode endplate 104. In known manner, fastening means, such as nuts, bolts, washers and the like are provided for clamping together the fuel cell unit 100 and the entire fuel cell stack.

Still referring to Figure 1, the endplate 104 is provided with a plurality of connection ports for the supply of various fluids. Specifically, the second endplate 104 has first and a second air connection ports 106, 107, first and second coolant connection ports 108, 109, and first and second hydrogen connection ports 110, 111. As will be understood by those skilled in the art, the MEA 124, the anode and cathode flow field plates 120, 130, the first and second current collector plates 116, 118, the first and second insulator plates 112, 114, and the first and/or second end plates 102, 104 have three inlets near one end and three outlets near the opposite end thereof, which are in alignment to form fluid ducts for air as an oxidant, a coolant, and hydrogen as a fuel. Also, it is not essential that all the outlets be located at one end, i.e., pairs of flows could be counter current as opposed to flowing in the same direction. The inlet and outlet regions of each plate are also referred to as manifold areas. Although not shown, it will be understood that the various ports 106 - 111 are fluidly connected to ducts that extend along the length of the fuel cell unit 100.

In the fuel cell stack shown in Figure 1, the fuel cell stack runs in "closed-end" mode, which means process fluids and coolant are supplied to and discharged from same end of the fuel cell stack. In other cases, the fuel cell stack may run in "flow-through" mode, which means process fluids and coolant enter the fuel cell stack from one end and leaves the stack from the opposite end thereof. This requires the first end plate 102 be provided with corresponding connection ports for process fluids.

Referring now to Figures 2 to 10, these show a first embodiment of the end plate 200 according to the present invention. Hereinafter, the designations "outer face" and "inner face" with respect to end plates respectively indicate the side facing away from the fuel cells located within the stack and the side facing towards the fuel cells located within the stack. The end plate 200 has an outer face 220 and an inner face 240. In this particular embodiment, the end plates 200 has two opposite end faces 260 and 280 in the longitudinal direction. Three connection ports 201, 203 and 205 are provided on the end face 260 and another three connection ports 202, 204 and 206 are provided on the opposite end face 280. It is to be understood that the end plate 200 could be in square shape instead of rectangular and the connection ports may be provided on the two opposite end faces in the lateral direction. However, the shape of the end plate and the position of the connection ports do not form part of the present invention.

The inner face 240 of the end plate 200 has a central region 250 and a peripheral region 255 surrounding the central region 250. The connection ports 201- 206 extend from their associated end faces 260, 280 along longitudinal direction of the end plate 200 toward the inside thereof to a certain extend and then extend in a direction substantially perpendicular to the inner face 240 and the outer face 220, toward the inner face 240 and form openings thereon. In other words, each of the connection ports 201-206 is in the form of two blind holes perpendicular to and in fluid communication with each other. The openings on the inner face 240 are still indicated herein with same reference numbers. As

shown in the figures, the openings 201-206 are located in the peripheral region 255. A plurality of cavities 290 are provided in the central region 250. The plurality of cavities 290 are preferably disposed such that they align in both longitudinal and lateral directions, and hence an array of cavities is formed in the central region 250. The cavities 290 are round, blind holes provided on the inner face 240, and preferably have substantially same dimension. They extend along the thickness direction of the end plate 200 to a certain extent. The depth of the cavities 290 is in the range of 40% - 80% of the thickness of the end plate 200 and preferably in the range of 60% - 80%. The presence of the cavities 290 reduces the material and hence weight of the end plate 200. When a fuel cell stack is assembled, the entire inner face 240 engages with an insulator plate. Therefore, with pressure applied from ends of the stack and the cavities being provided on the inner face 240, the end plate 200 maintains its robustness in spite of cavities. The insulator plate is followed by a current collector plate (also known as terminal plate or bus bar). All three plates are joined together with bolts, as will be described below. The bolted assembly is much stronger than otherwise. In conventional stack design, the three plates are simply juxtaposed or stacked together. The present assembly, with its laminar structure, is much stiffer than three loose pieces, but retains its light weight. It is also possible to bond all three plates together to using conventional bonding methods. This would be an excellent way to form the assembly to ensure that the components are held together during assembly, to ensure no shorting through the components, and to create an even stiffer package.

The peripheral region 255 of the end plate 200 is provided with a plurality of through holes 228. The through holes are adapted to accommodate tie rods. In this embodiment, four blind holes 226 are provided in the peripheral region 255 through which bolts can be inserted. Although not shown in this embodiment, it is easy to understand that the bolts pass through the corresponding through holes in insulator plate and the current collector plate, bolting the three plates together. The through holes 228 can also be threaded

holes or blind holes. On the end faces 260, 280, a plurality of threaded holes 230 are provided around each of the connection ports 201-206 for securing fitting onto the end faces such that process fluids can be supplied to and directed out of the fuel cell stack through the connection ports 201-206. On the side faces of the end plate 200, a plurality of positioning notches 224 are provided to facilitate the alignment of the end plate 200 and possibly fuel cell flow field plates (not shown) during assembly of the fuel cell stack. As can be seen in the figures, the inner face 240 of the end plate 200 is substantially flat such that pressure can be uniformly passed on to insulator plate and hence the fuel cells within the stack. Each end of the end plate 200 has an inclined portion 222 on the outer face 220. The thickness and height of the end plate 200 is gradually reduced. This further reduces the dimension and hence weight of the end plate 200.

Figures 11 to 18 show a second embodiment of the end plate 300 according to the present invention. In the following embodiments, components similar to those in the first embodiment are indicated with similar reference numbers with a different prefix. Specifically, in the second embodiment, components are indicated with reference numbers beginning with "3". In the second embodiment, the end plate 300 has an outer face 320 and an inner face 340. The end plates 300 has two opposite end faces 360 and 380 in the longitudinal direction. It is to be understood that the end plate 300 could be in square shape in stead of rectangular and the connection ports may be provided on the two opposite end faces in the lateral direction. A first manifold region 370 is provided near on the end face 360 and a second manifold region 372 near the opposite end face 380. On the inner face 340, three connection ports 301, 303 and 305 are provided in the first manifold region 370 and three connection ports 302, 304 and 308 are provided in the second manifold region 372. On the outer face 320, three connection ports 311, 313 and 315 are provided in the first manifold region 370 and three connection ports 312, 314 and 316 are provided in the second manifold region 372. The connection ports 301-306 fluidly communicate respectively with connection ports 311- 316 to allow respective

process fluids to flow from outer face 320 to inner face 340 and into the fuel cells within the fuel cell stack.

5 The connection ports 301-306 and 311-316 can take various shapes or forms. In this embodiment, on the inner face 340, the connection ports 301-306 are shaped such that they match the shape of inlet and outlet apertures of the adjacent plate within the fuel cell stack to minimize leakage of process fluids. On the outer face 320, each of the connection ports 311-316, for example, connection port 311, has a counter bore 311a with enlarged diameter and an
10 inner bore 311b with reduced diameter. The inner bore 311b communicates with the corresponding connection port 301 provided on inner face 340 of the end plate 300. On the bottom face 311c of the counter bore 311a, a plurality of threaded holes 382 are provided. Threaded holes 382 are also provided on the bottom face of the counter bore of each connection port 312-316 for connection
15 to external ducts or hoses.

The inner face 340 of the end plate 300 has a central region 350 and a peripheral region 355 surrounding the central region 350. A plurality of cavities 390 are provided in the central region 350. The plurality of cavities 390 are
20 preferably disposed such that they align in both longitudinal and lateral directions, and hence an array of cavities is formed in the central region 350. The cavities 390 are round, blind holes provided on the inner face 340, and preferably have substantially same dimension. They extend along the thickness direction of the end plate 300 to a certain extent. The depth of the cavities 390 is in the range of
25 40% - 80% of the thickness of the end plate 300 and preferably in the range of 60% - 80%. The presence of the cavities 390 reduces the material and hence weight of the end plate 300 while maintains its robustness.

The peripheral region 355 of the end plate 300 is provided with a
30 plurality of through holes 328. The through holes are adapted to accommodate tie rods. In this embodiment, four blind holes 326 are provided in the peripheral

region 355 through which bolts can be inserted to secure the end plate, an insulator plate and a current collector plate (not shown) together in the same manner as described above. The through holes 328 can also be threaded holes or blind holes. On the side faces of the end plate 300, a plurality of positioning
5 notches 324 are provided to facilitate the alignment of the end plate 300 and possibly fuel cell flow field plates (not shown) during assembly of the fuel cell stack. As can be seen in the figures, the inner face 340 of the end plate 300 is flat such that pressure can be uniformly passed on to insulator plate and hence the fuel cells within the stack. The thickness and height of each manifold region
10 370 and 372 of the end plate 300 on the outer face 320 is gradually reduced. This further reduces the dimension and hence weight of the end plate 300.

Figures 19 to 27 show a third embodiment of the end plate 400 in accordance with the present invention. The third embodiment of the end plate
15 400 is similar to the second embodiment and hence is not described in detail herein. The inner face 440 of the third embodiment of the end plate 400 also has a central region 450 and a peripheral region 455 surrounding the central region 450. A plurality of central cavities 490 are provided in the central region 450. The plurality of central cavities 490 are preferably disposed such that they align in
20 both longitudinal and lateral directions, and hence an array of cavities is formed in the central region 450. The central cavities 490 are round, blind holes provided on the inner face 440, and preferably have substantially same dimension. They extend along the thickness direction of the end plate 400 to a certain extent. The depth of the central cavities 490 is in the range of 40%-80% of the thickness of
25 the end plate 400 and preferably in the range of 60%-80%. The end plate 400 is further provided with a plurality of peripheral cavities 495 in the peripheral region 455. The dimensions of each peripheral cavity may not be the same. As can be seen in the figures, peripheral cavities 495 near each side face of the end plate 400 may be rectangular in shape while those near each corner may be
30 substantially triangular. The peripheral cavities 495 are also blind holes provided on the inner face 440. The depth of the peripheral cavities 495 is in the range of

40%-80% of the thickness of the end plate 400 and preferably in the range of 60%-80%. The presence of the peripheral cavities 495 further reduces the material and hence weight of the end plate 400 while still maintains its robustness. In this embodiment, four blind holes 426 are provided in the central region 450 on the inner face 440 of the end plate 400 for accommodating bolts that bolts the end plate, and insulator plate and a current collector plate (not shown) in the manner described above.

Figures 28 to 35 show a fourth embodiment of the end plate 500 in accordance with the present invention. The fourth embodiment of the end plate 500 is similar to the third embodiment of the end plate 400 and hence will not be described in detail herein. The end plate 500 also has, on its inner face 540, central cavities 590 in the central region 550 and peripheral cavities 595 in the peripheral region 555 surrounding the central region 550, as in the third embodiment. The difference from the third embodiment is that the end plate 500 is not provided with connection ports for connecting to process fluids. This end plate can be used in same manner as the end plate 102 in Figure 1. In this embodiment, more areas are made available for either central cavities 590 or peripheral cavities 495 because of the absence of connection ports. This further reduces the weight of the end plate 500. The central cavities 590 and the peripheral cavities are all blind holes. The central cavities 590 may have a depth in the range of 40%-80% of the thickness of the end plate 400 and preferably in the range of 60%-80%. The peripheral cavities 595 may have a depth in the range of 40%-80% of the thickness of the end plate 400 and preferably in the range of 60%-80%. In this embodiment, four blind holes 526 are provided in the central region 550 on the inner face 540 of the end plate 500 for accommodating bolts that bolts the end plate, and insulator plate and a current collector plate (not shown) in the manner described above.

Figure 36 illustrate the assembly of the end plate 500, an insulator plate and a current collector plate (terminal plate) assembled together. The

insulator and the current collector plate are not provided with inlets and outlets for fuel cell reactant. However, it is possible to provide them where they are desired. Four holes are shown in the figure, in the central region. However, the holes can be provided in other regions and the number of holes can be different. It can be appreciated that in other embodiments, the three plates are bolted (or bonded) together in similar way.

It can be appreciated that the shape of the end plate is also not limited to that shown in the accompanying figures. For example, the end plate can be circular, oval and other shapes. Moreover, the shape of connection ports can vary. It is also to be understood that the present invention is also applicable to end plates of other electrochemical cells, such as electrolyzers.

It is anticipated that those having ordinary skills in the art can make various modifications to the embodiments disclosed herein after learning the teaching of the present invention. For example, the number and arrangement of components in the system might be different, different elements might be used to achieve the same specific function. However, these modifications should be considered to fall under the protection scope of the invention as defined in the following claims.

Claims:

1. An end plate for an electrochemical cell stack, comprises an outer face and an inner face, wherein a plurality of cavities are provided on the inner face.
2. An end plate for an electrochemical cell stack as claimed in claim 1, wherein the inner face comprises a central region and a peripheral region surrounding the central region and a first plurality of cavities are provided in the central region.
3. An end plate for an electrochemical cell stack as claimed in claim 2, wherein the first plurality of cavities form an array of cavities.
4. An end plate for an electrochemical cell stack as claimed in claim 3, wherein the first plurality of cavities are disposed such that they align in longitudinal and lateral directions.
5. An end plate for an electrochemical cell stack as claimed in claim 4, wherein the depth of the first plurality of cavities is in the range of 40%-80% of the thickness of the end plate.
6. An end plate for an electrochemical cell stack as claimed in claim 5, wherein the depth of the first plurality of cavities is in the range of 60%-80% of the thickness of the end plate.
7. An end plate for an electrochemical cell stack as claimed in claim 6, wherein each cavity in the first plurality of cavities has substantially same depth.

8. An end plate for an electrochemical cell stack as claimed in claim 7, wherein each cavity in the first plurality of cavities is a round blind hole having same diameter.
9. An end plate for an electrochemical cell stack as claimed in claim 8, wherein a second plurality of cavities are provided in the peripheral region.
10. An end plate for an electrochemical cell stack as claimed in claim 9, wherein the depth of the second plurality of cavities is in the range of 40%-80% of the thickness of the end plate.
11. An end plate for an electrochemical cell stack as claimed in claim 10, wherein the depth of the second plurality of cavities is in the range of 60%-80% of the thickness of the end plate.
12. An end plate for an electrochemical cell stack as claimed in claim 11, wherein each cavity in the second plurality of cavities has substantially same depth.
13. An end plate assembly for an electrochemical cell stack, comprises:
 - an end plate having a first inner face, a first outer face and at least one blind hole on the inner face,
 - an insulator plate having a corresponding number of first through holes;
 - and
 - a terminal plate having a corresponding number of second through holes;
 - wherein a corresponding number of bolts pass through the first and second through holes and the blind holes of the end plate to secure to the end plate, the insulator plate and the terminal plate together such that the insulator plate abuts against the inner face of the end plate and the terminal plate abuts against the insulator plate.

ABSTRACT

An end plate for an electrochemical cell stack, comprises an outer face and an inner face, wherein a plurality of cavities are provided on the inner face. The inner face comprises a central region and a peripheral region surrounding the central region and a first plurality of cavities are provided in the central region forming an array of cavities. The end plate further comprises a second plurality of cavities in the peripheral region.

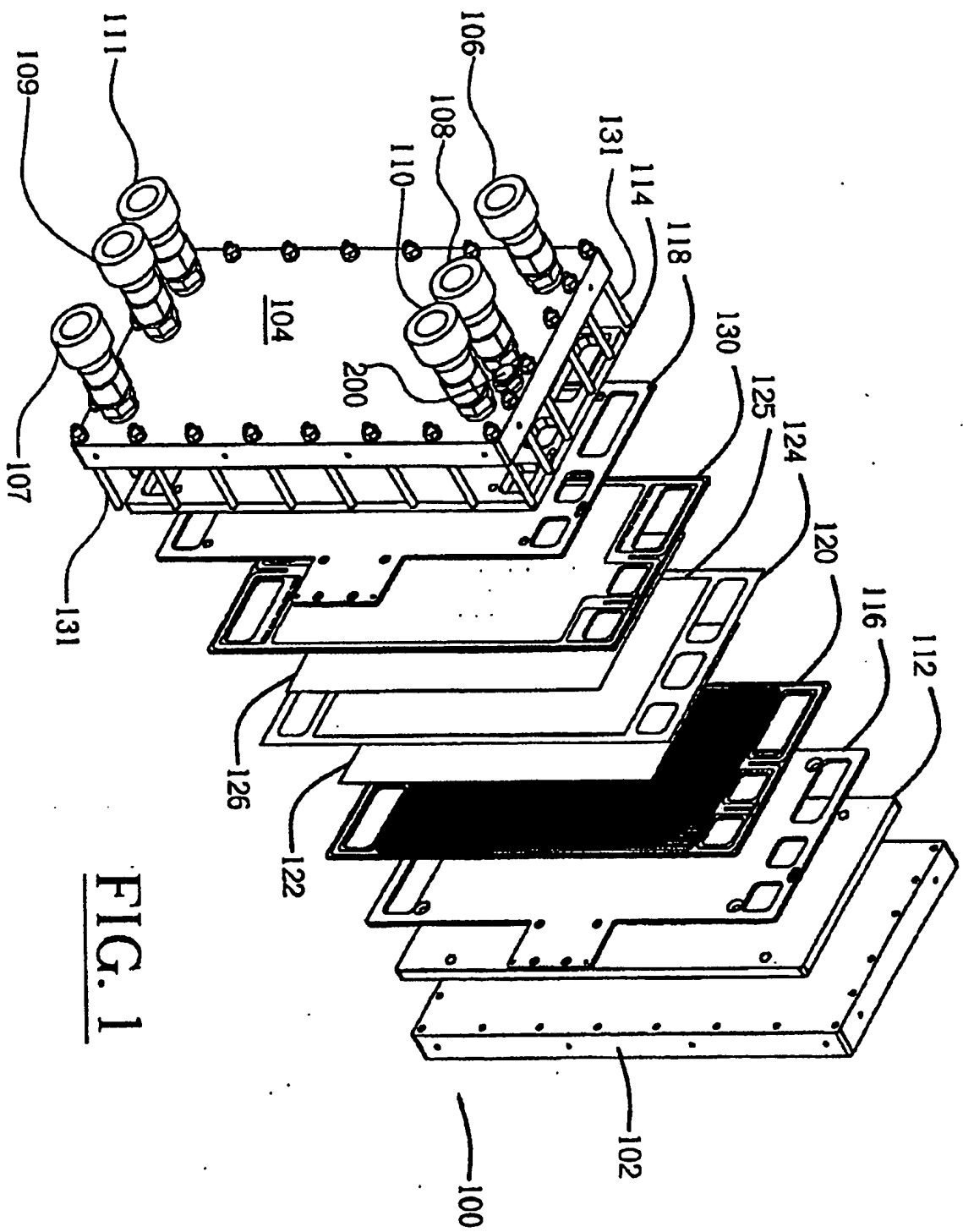
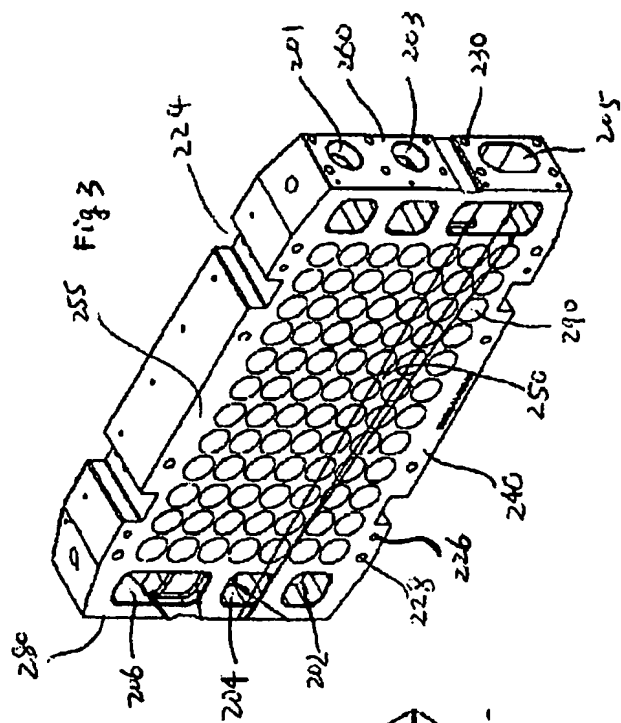
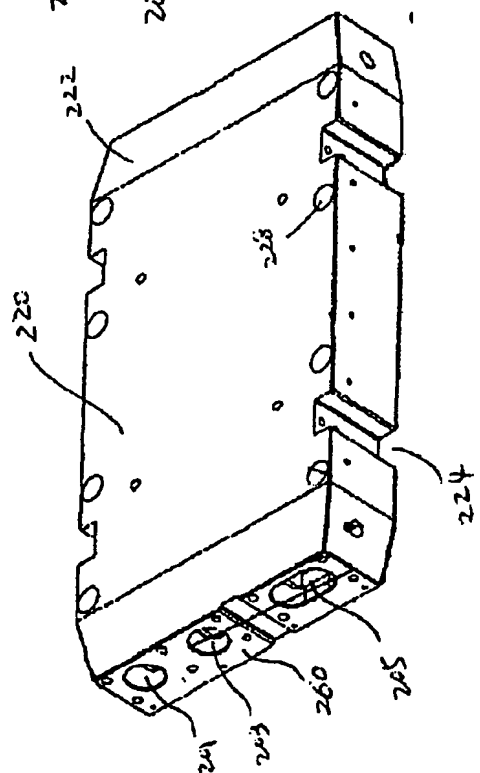


FIG. 1



F.g 2

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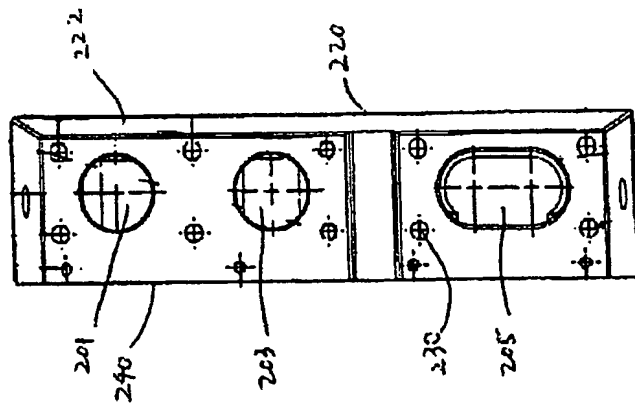


Fig. 5.

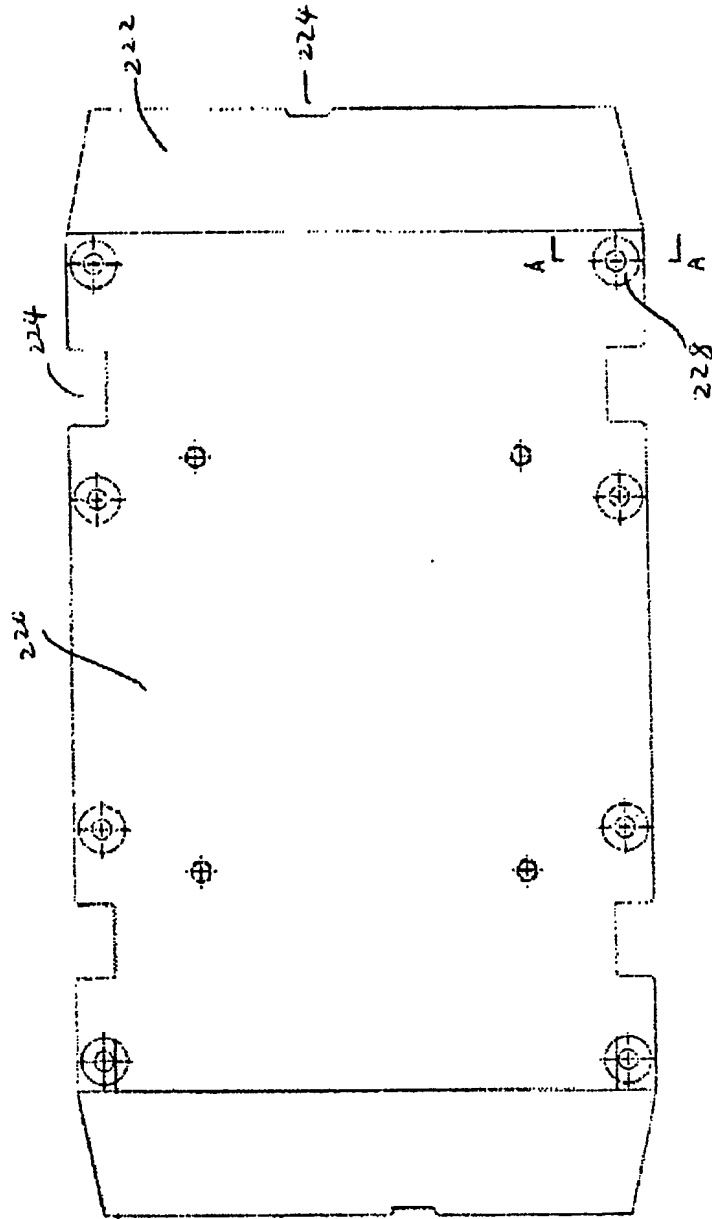
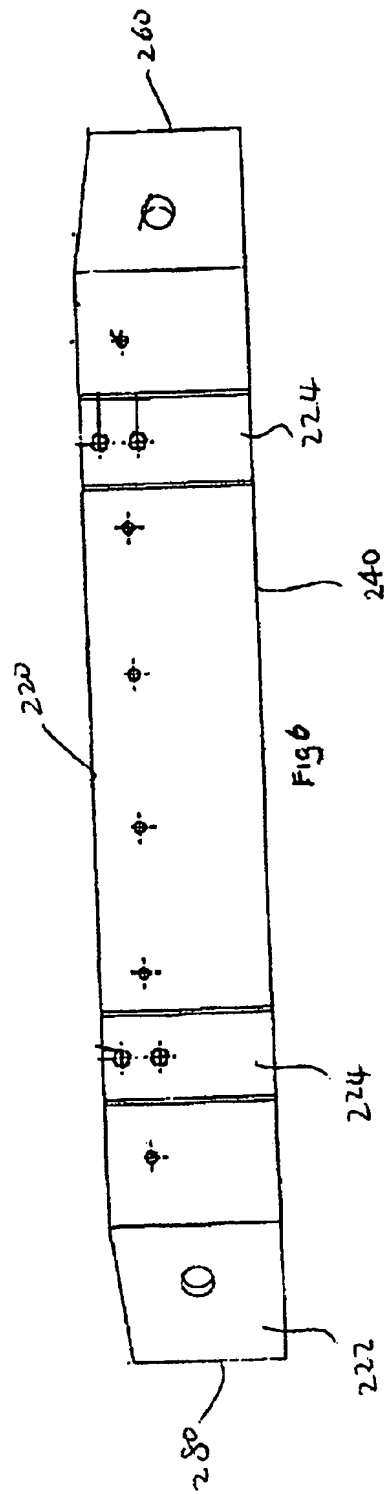
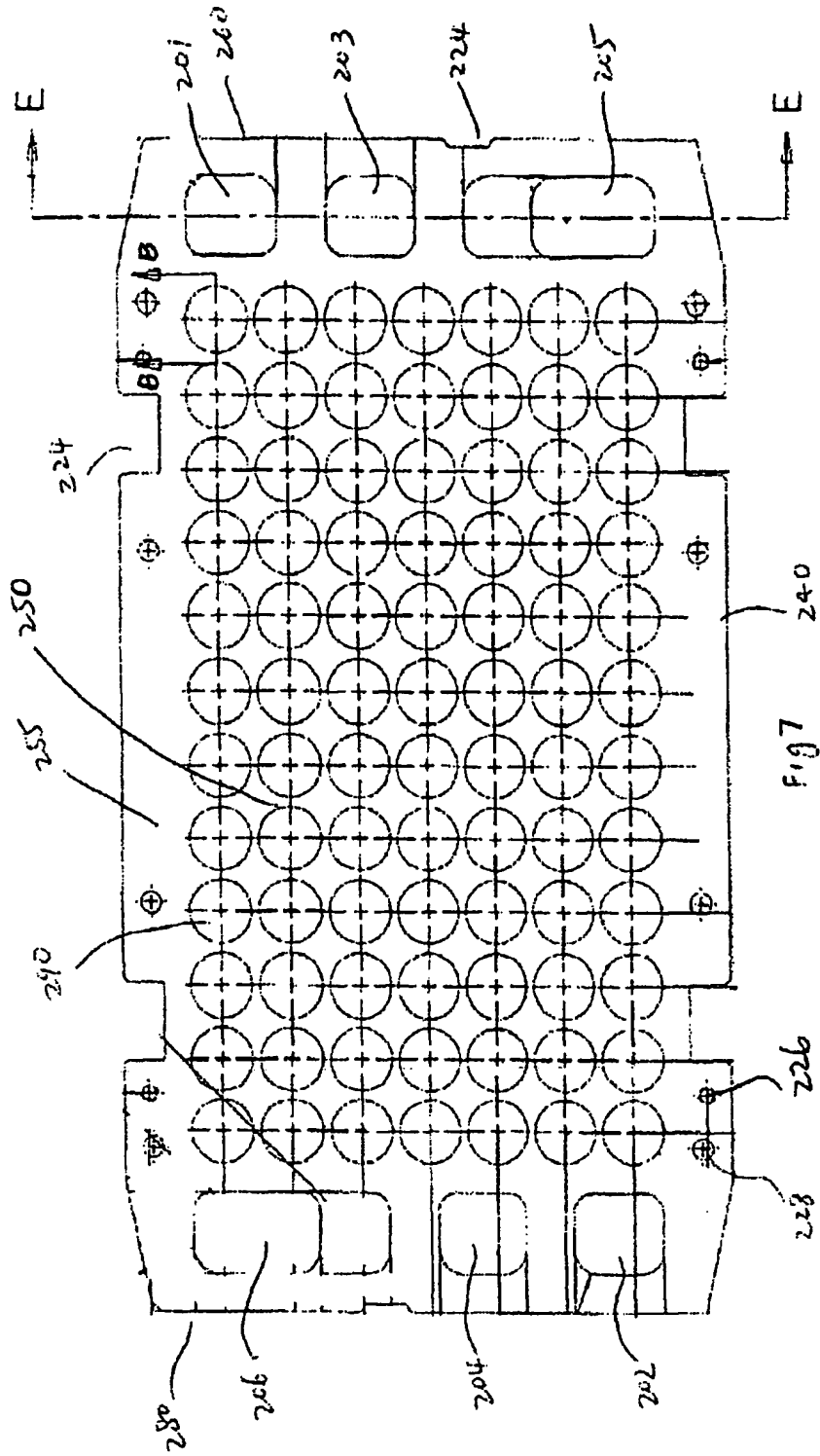


Fig. 4.





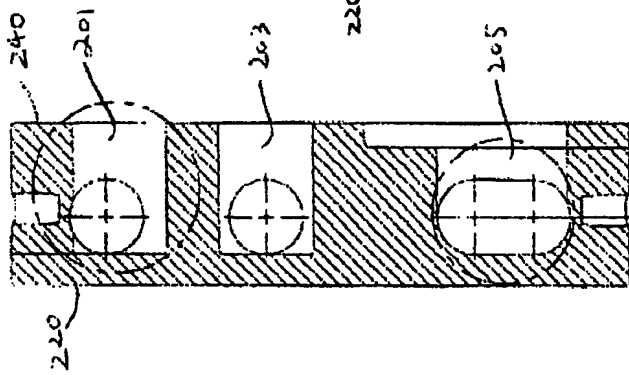


Fig. 8

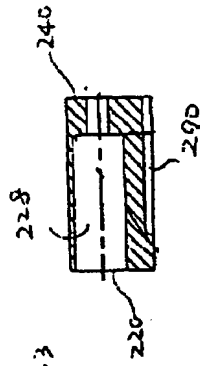


Fig. 9

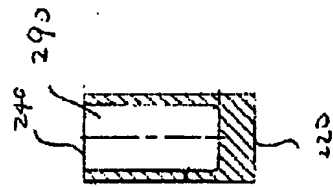


Fig. 10

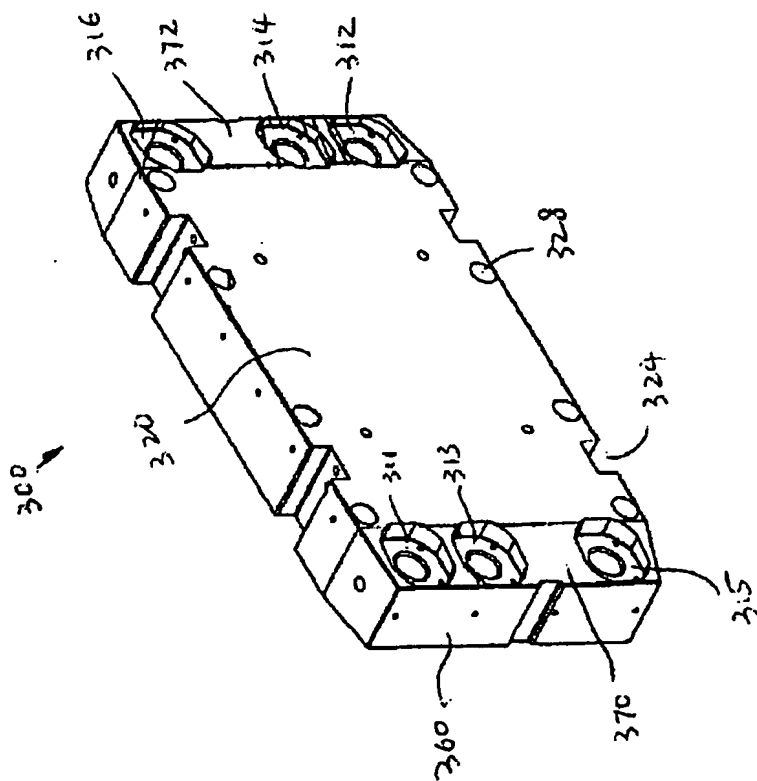


Fig. 11

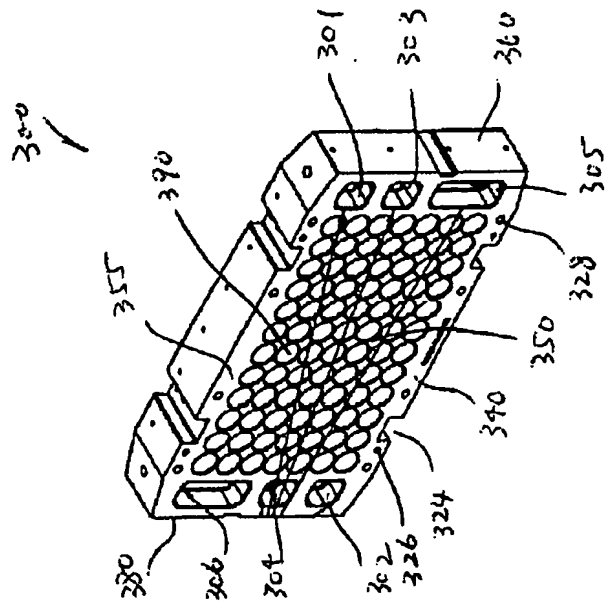


Fig. 12

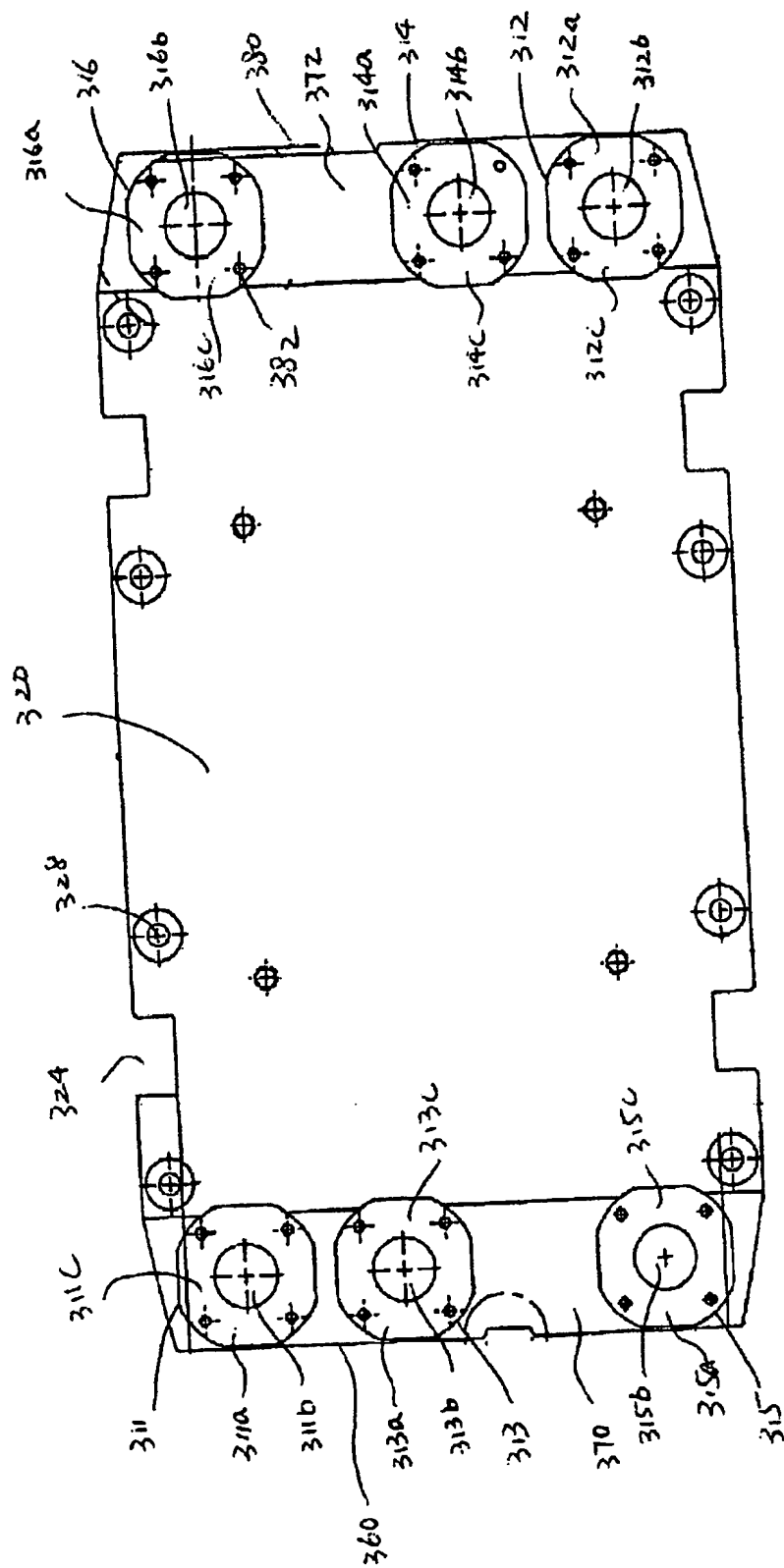


Fig 13

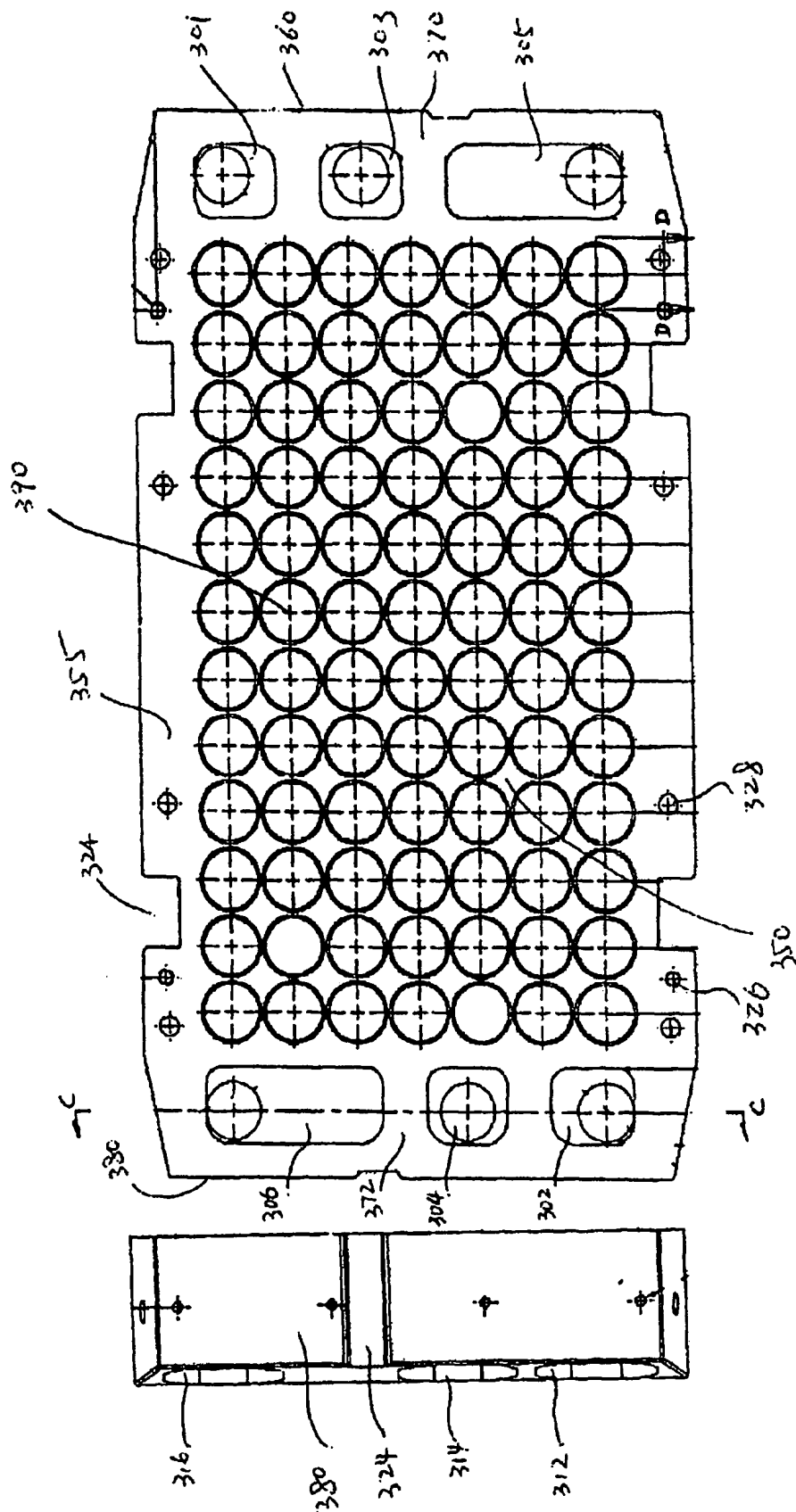


Fig 14

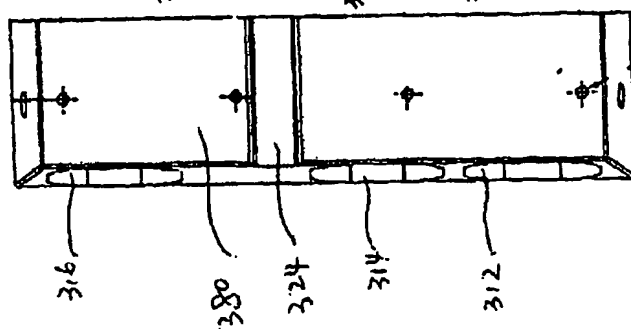


Fig 15

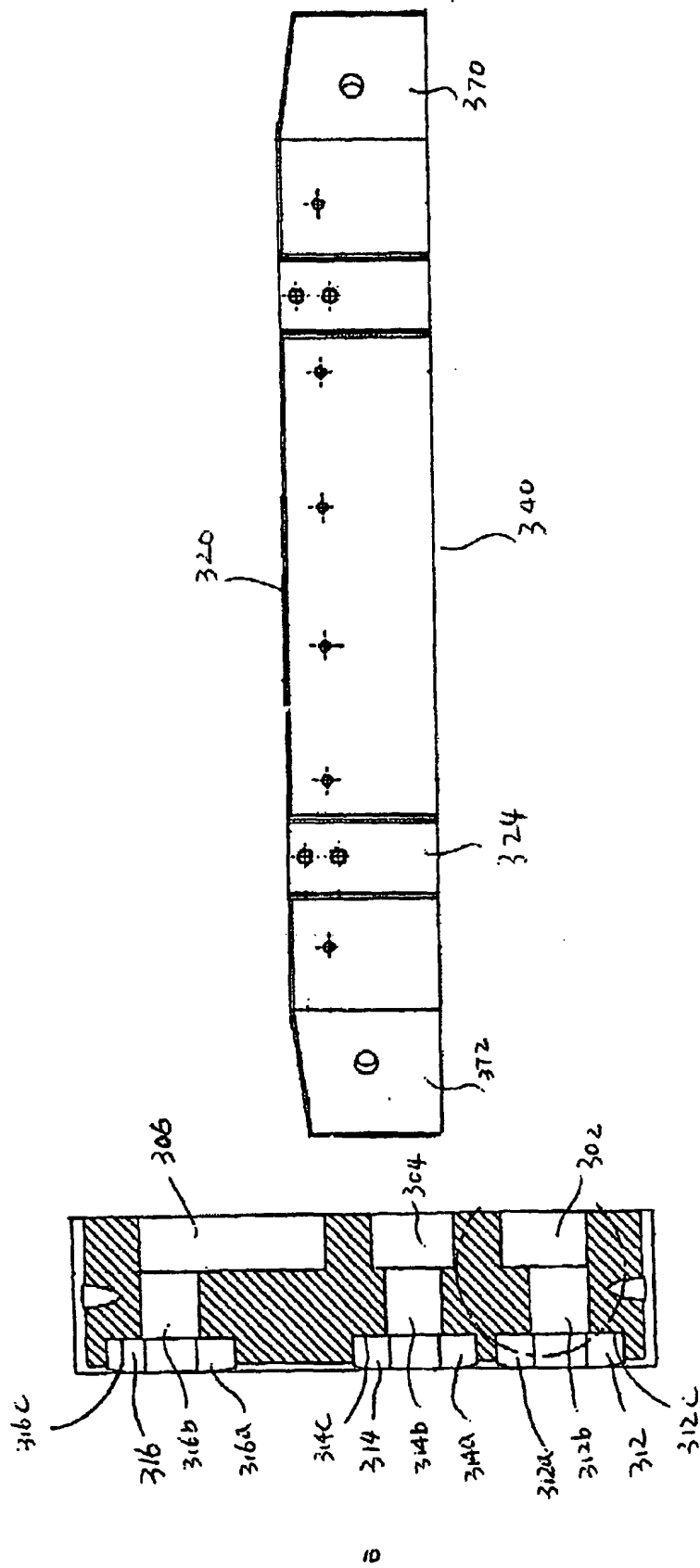


Fig. 16

Fig. 17

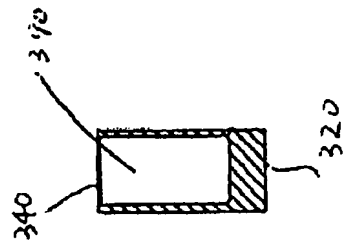


Fig. 13

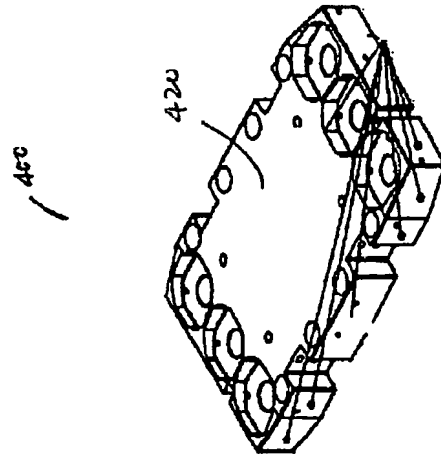


Fig. 19

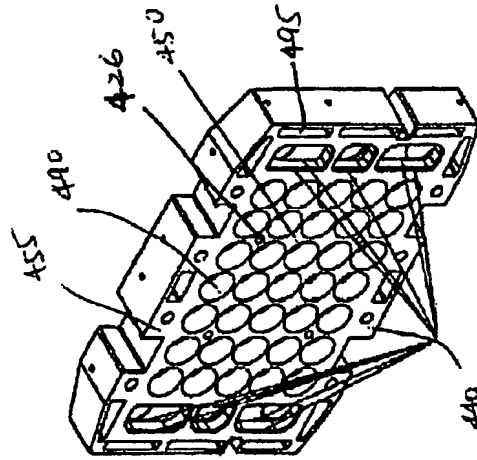


Fig. 20

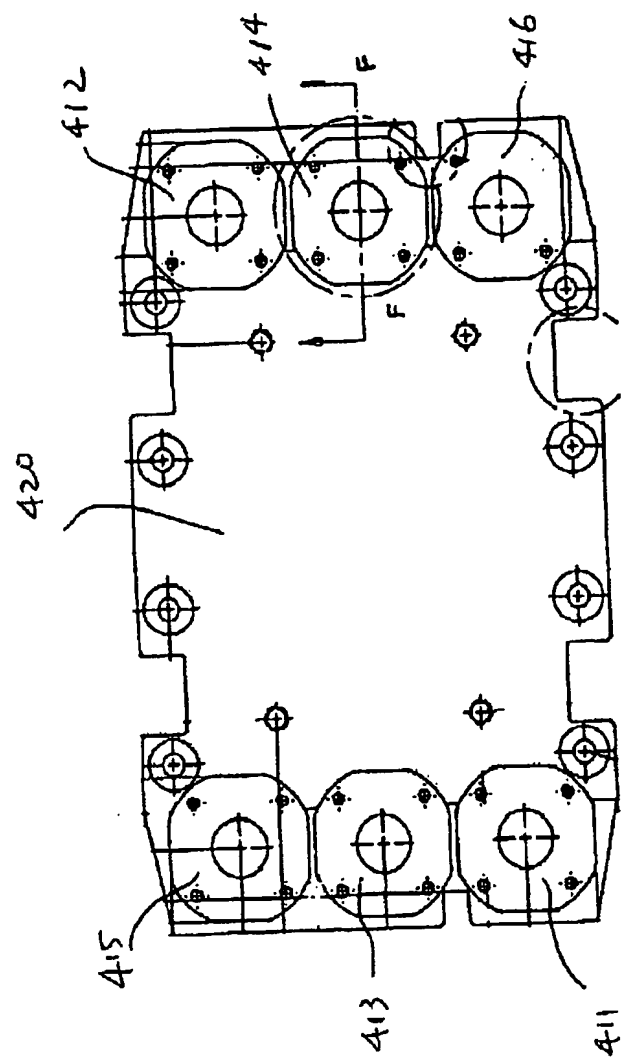


Fig. 21

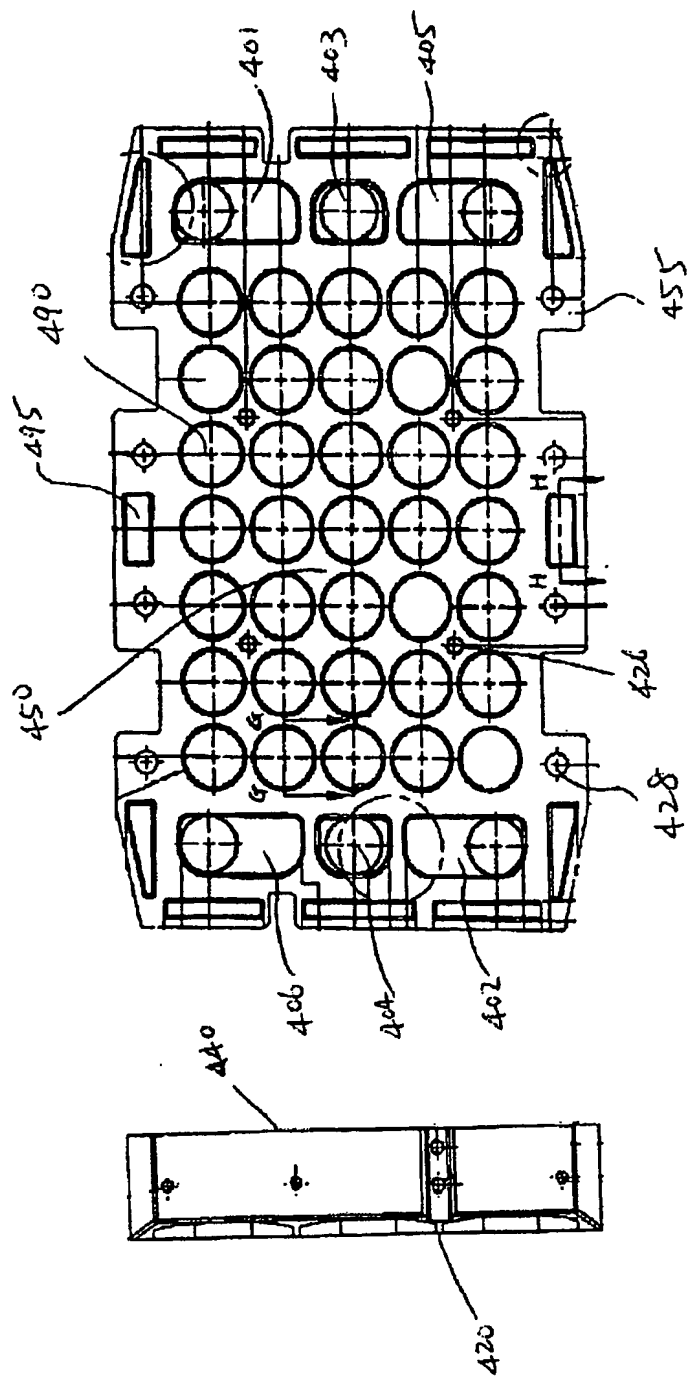


Fig. 22

Fig. 23

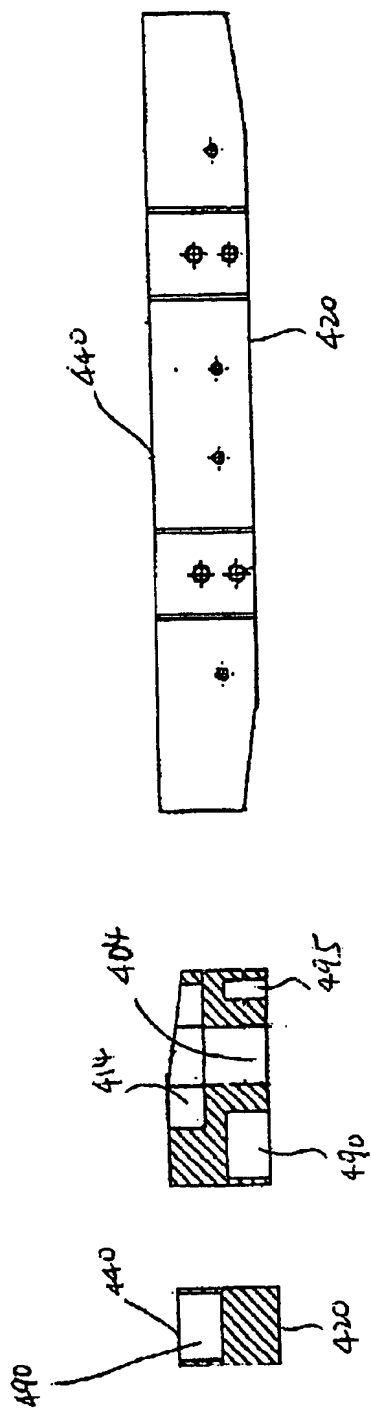


Fig. 24

Fig. 25

Fig. 26

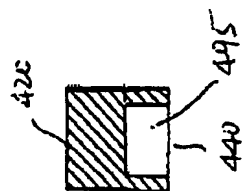


Fig. 27

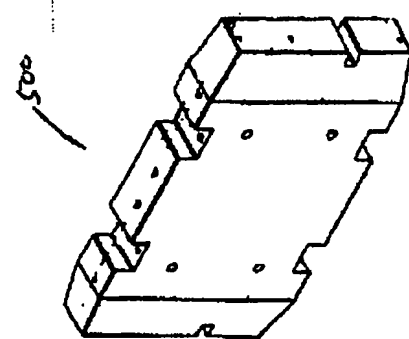


Fig. 28

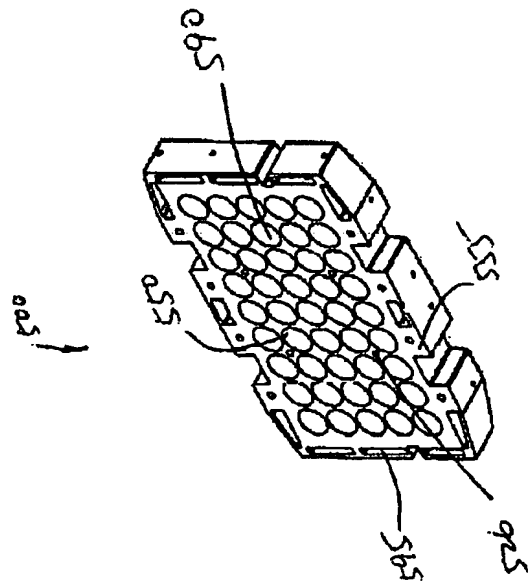


Fig. 29

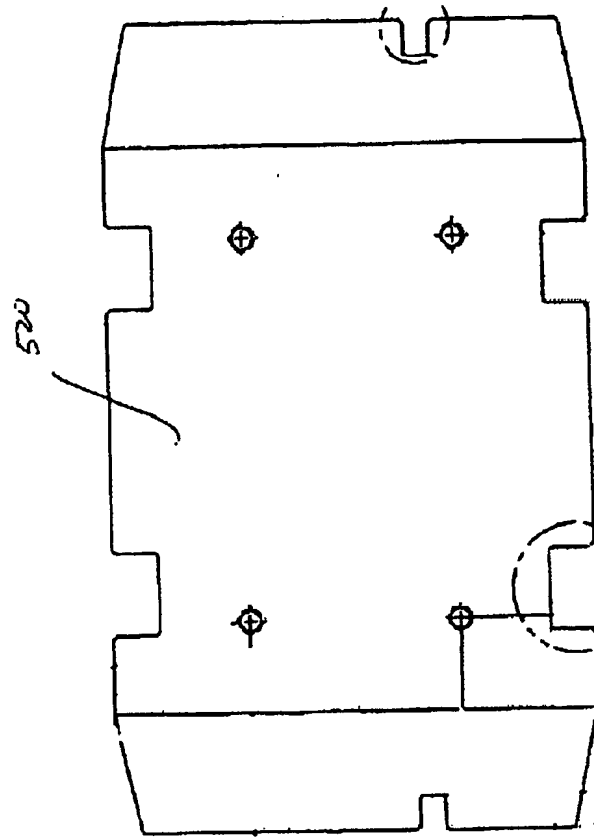


Fig 30

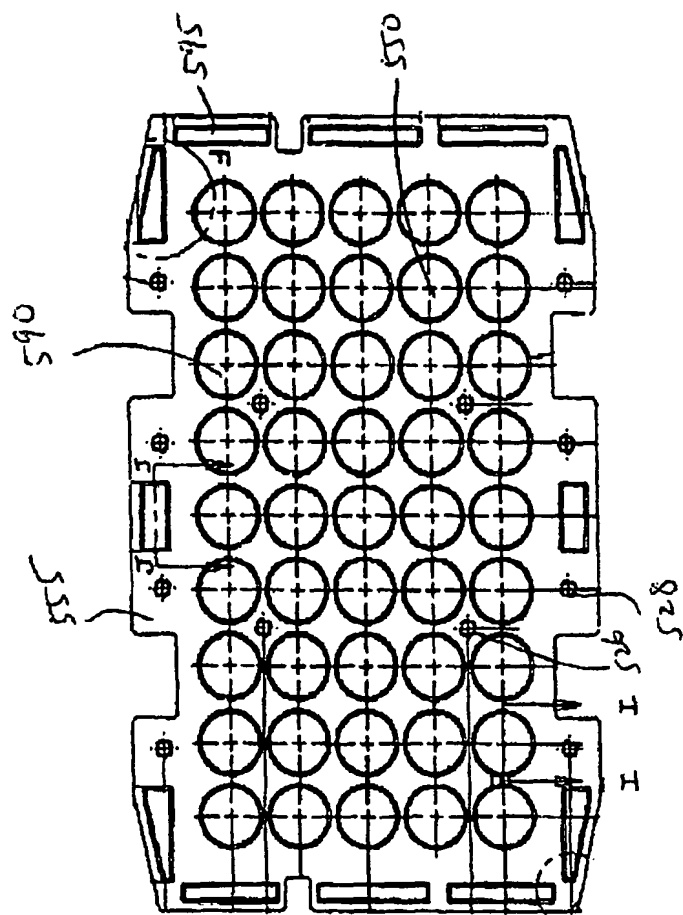


Fig. 31

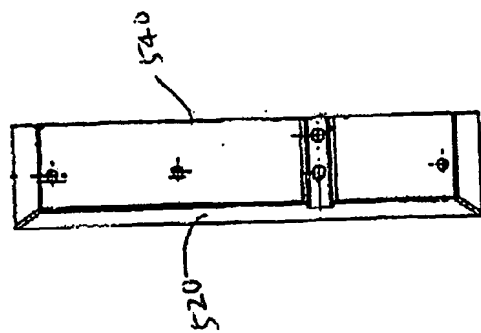


Fig. 32

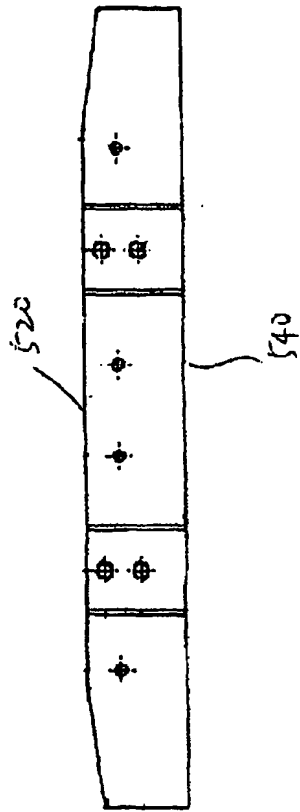


Fig. 33

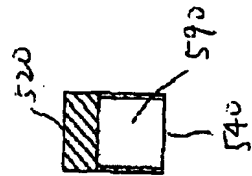


Fig. 34

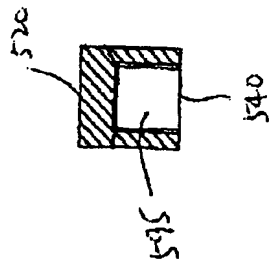


Fig. 35

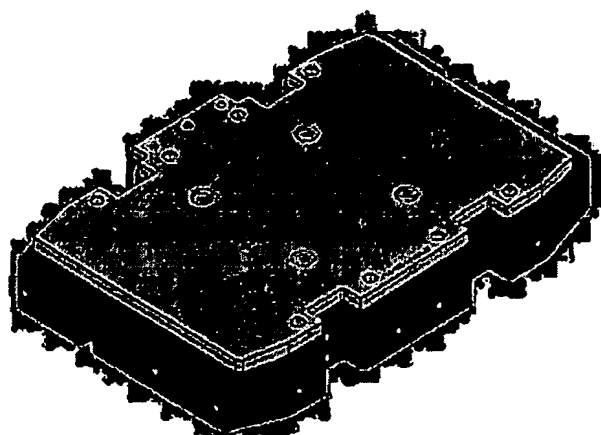


Fig 36

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